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LANCE CONFIGURATION Q-FLEX ACCELEROMETER DESIGN VERIFICATION.(U)
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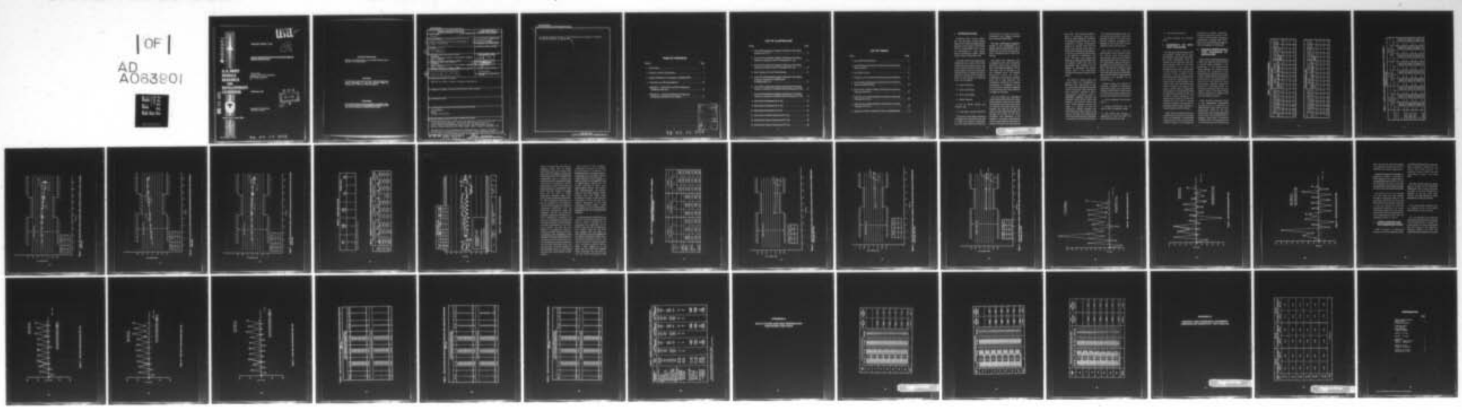

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TECHNICAL REPORT T-78-91

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LANCE CONFIGURATION Q-FLEX ACCELEROMETER DESIGN VERIFICATION

Joe S. Hunter
Guidance and Control Directorate
Technology Laboratory

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

6 September 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Sundstrand Data Control (SDC), Inc. was awarded a contract during August 1977 to perform design analysis, fabrication and testing on three (3) Quartz Flexure Accelerometers built to meet the requirements of Lance Missile Interim Specification (MIS) Number 13227C, dated 24 September 1975.

The main thrust of the program with Sundstrand was to improve the Q-Flex Accelerometer performance in the area of bias thermal hysteresis (BTH)

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The design analysis portion of the program was performed to establish alternative methods to improve BTH.

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1. INTRODUCTION

Sundstrand Data Control (SDC), Inc., was awarded a contract during August 1977, to perform design analysis, fabrication and testing on three Quartz Flexure Accelerometers built to meet the requirements of Lance Missile Interim Specification (MIS) Number 13227C, dated 24 September 1975.

The main thrust of the program with Sundstrand was to improve the Q-Flex Accelerometer performance in the area of bias thermal hysteresis (BTH). The design analysis portion of the program was performed to establish alternative methods to improve BTH. During the course of the analysis, the following areas were investigated:

- Magnet Matching
- Cubic Self-Heating
- Servo Loop Design
- Bobbin Material
- Use of Welded Pickoff and Torquer Leads
- Proof Mass Assembly Sensitivity

The purpose of the magnet matching investigation for the Q-Flex sensor was to reduce the quadratic nonlinearity term. The effectiveness of the match was determined through vibration rectification tests. Magnet matching does not directly affect BTH.

The cubic self-heating investigation resulted in the incorporation of a negative temperature coefficient resistor (NTCR) for use in the output circuit to reduce nonlinearity due to sensor self-heating.

The Lance servo electronics were reconfigured for use with the standard production Q-Flex sensor during the servo loop design investigation. The Q-Flex sensor uses air damping as one servo damping source. The standard production sensor has had a modification incorporated to eliminate errors due to static electricity. This modification reduced the air damping, necessitating a modification of the Lance electronics, originally configured for a special sensor for Lance, which had the higher air damping.

The first design area investigated which directly affects bias was torquer bobbin material. There are two torque coil bobbins in the Q-Flex sensor which are attached to the quartz reed with an adhesive. Any stress on the reed will cause it to warp and produce a bias error through the action of the servo electronics. The attachment of the bobbins to the quartz reed produces stress through differential expansion of dissimilar materials and, thus, produces

bias errors. The standard bobbin is made of aluminum, which has a relatively high temperature coefficient of expansion compared to quartz. As the temperature is varied, the aluminum expands or contracts more than the quartz reed, and this causes stress to build up at the interface in the adhesive. A bias error is produced when the stress in the adhesive is transferred to the quartz. This bias error changes with temperature. Bias instability will result if the adhesive yields with time and temperature. Bias instability can be reduced by fabricating the torquer bobbin from a low temperature coefficient of expansion material such as quartz.

The effects of welded pickoff and torquer leads were investigated to determine their contribution to bias error. In the past, Sundstrand has made pickoff and torquer lead connections with electrically conductive epoxy. Temperature variations cause a differential expansion between the conductive epoxy and the quartz reed substrate and produce output bias errors. These induced errors are not stable as a function of time and temperature. Similar problems exist when conductive epoxy is used on the torquer coil leads. The welded pickoff and torquer leads tasks were undertaken in an attempt to resolve these problems.

The last design analysis area to be investigated was related to proof mass assembly sensitivity. The proof mass assembly sensitivity investigation was designed to look at the effects of bias instability rather than the causes.

The three quartz flexure accelerometers were to be built to meet the design and performance requirements outlined in MIS 13227C, dated 24 September 1975. In addition to the requirements outlined in the above specification, the accelerometer bias at 80° F was specified to within plus and minus 50 μg of its initial 80° F value after each period of stabilization above and below 80° F. High-reliability components were specified for all electronic parts.

Program testing was directed at verifying acceptable accelerometer performance under the requirements outlined in MIS 123227C. The following tests were performed by Sundstrand on the three quartz flexure accelerometers:

- Initial acceptance test procedure (ATP)

- High-g nonlinearity over the -40° F to 200° F temperature range

- Bias stability after exposure to temperature of -65° F and 200° F (25 cycles minimum each test unit)

- Non-operating vibration

- Final acceptance test procedure (ATP)

2. SUMMARY OF SDC TEST PROGRAM

The data generated during the SDC test program showed that all three accelerometers performed well within the Lance specification with the exception of spin sensitivity. Since the spin sensitivity results on the three accelerometers were near the specification limit, sensor yield became of some concern. To quantify this potential yield problem, SDC performed an analysis to determine the spin sensitivity magnitudes to be expected from various possible error sources. More than 100 sensors were tested to support the analysis. The analysis showed that the magnitudes experienced were essentially what would be expected based upon the part and assembly testing tolerances. The analysis and test data on the 100 units indicated that the yield in quantity production would be very high for this parameter and that no part, assembly, or tooling changes would be required.

Table 1 shows the data from the pre-environmental and post-environmental ATP's at Sundstrand. Accelerometer nonlinearity test results are summarized in *Table 2*. *Figures 1, 2,* and *3* depict the nonlinearity at ambient temperature and at the temperature extremes. *Table 3* shows the bias stability through all environments, including both ATP's. *Figure 4* is a plot of the bias through the entire test sequence at Sundstrand.

3. DESIGN VERIFICATION TEST PROGRAM AT MIRADCOM

Many of the tests that were conducted at SDC were repeated at MIRADCOM to provide added confidence in the performance of the accelerometers. Special emphasis was directed toward evaluating the accelerometer bias thermal hysteresis (BTH) characteristics because problems had been experienced in that area on a previous program. A Manufacturing Methods and Technology (MM&T) program, directed at improving BTH, was conducted concurrently with the Lance program. Many of the improvements made in BTH can be attributed to the successful MM&T program.

Table 4 provides a summary of some of the accelerometer performance characteristics evaluated at MIRADCOM. Scale factor and bias performance shown in the table represent the value of these parameters at the outset of the MIRADCOM test program. Scale Factor Temperature Coefficient (SFTC) performance proved to be extremely good, with performance

TABLE 1. LANCE ATP DATA SUMMARY

BEFORE ENVIRONMENTAL TESTS

UNIT S/N	SF AND B RELATED VALUES: SF (V/g)	BIAS (mg)	SFTC (%/°F)	BTC (mg/°F)	ALIGNMENT: VM (mr)	HM (mr)	LINEARITY: HIGH g(%) 17-26 AVG	HIGH g(%) 33	IG (mg) 30°	IG (mg) 60°	VIBRATION: VRC (mg/g²) 5.3g	VRC (mg/g²) 1.3g	ΔSF (%)	SPIN TESTS: SENS. (mg/RPS²)	ECM (in.)	LEAK RATE (cc/sec)	RSS ERROR: BOOST	SUST.
01	0.49996	-0.037	0.0002	0.0015	0.064	-0.015	0.001	0.002	-0.002	-0.004	-0.001	0.006	0.002	-0.020	0.021	2 x 10 [illegible]	0.012	0.229
02	0.49997	-0.045	0.0002	0.0004	-0.049	-0.030	0.009	0.012	-0.008	-0.002	0.002	-0.001	0.001	0.034	0.022	2 x 10 [illegible]	0.024	0.374
03	0.49997	-0.012	0.0003	0.0006	-0.013	0.010	0.004	0.003	-0.003	-0.001	0.001	0.009	0.000	0.025	0.013	2 x 10 [illegible]	0.006	0.274
SPEC LIMIT	0.50000 ±.00125	0.200 ABS	0.0100	0.0060	0.500	1.50	0.020	0.030	.200	0.200	0.160	0.160	0.026	0.044	0.050	2 x 10 [illegible]	0.038	0.380

AFTER ENVIRONMENTAL TESTS

UNIT S/N	SF AND B RELATED VALUES: SF (V/g)	BIAS (mg)	SFTC (%/°F)	BTC (mg/°F)	ALIGNMENT: VM (mr)	HM (mr)	LINEARITY: HIGH g (%) 17-26 AVG	HIGH g (%) 33	IG (mg) 30°	IG (mg) 60°	VIBRATION: VRC (mg/g²) 5.3g	VRC (mg/g²) 1.3g	ΔSF (%)	SPIN TESTS: SENS (mg/RPS²)	ECM (in.)	LEAK RATE (cc/sec)	RSS ERROR: BOOST	SUST.
01	0.50012	-0.001	0.0002	0.0015	0.022	0.009	0.001	0.001	-0.007	-0.003	-0.001	0.005	0.003	-0.019	0.029	2 x 10 [illegible]	0.010	0.216
02	0.50013	-0.042	0.0002	0.0004	-0.080	0.080	0.006	0.010	-0.013	-0.009	-0.001	0.006	0.002	0.032	0.028	2 x 10 [illegible]	0.012	0.352
03	0.50014	0.006	0.0002	0.0004	0.020	-0.024	0.002	0.002	-0.004	0.002	0.002	0.007	0.003	0.024	0.022	2 x 10 [illegible]	0.007	0.263
SPEC LIMIT	0.50000 ±.00125	0.200 ABS	0.0100	0.0060	0.500	1.50	0.020	0.030	0.200	0.200	0.160	0.160	0.026	0.044	0.050	2 x 10 [illegible]	0.038	0.330

TABLE 2. LANCE Q-FLEX ACCELEROMETER NONLINEARITY TEST SUMMARY (TESTED AT SDC)

	S/N 101			S/N 102			S/N 103		
	NONLINEARITY (%)			NONLINEARITY (%)			NONLINEARITY (%)		
TEMPERATURE (°F)	17g	26g	33g	17g	26g	33g	17g	26g	33g
-40	0.0030 0.0014 -0.0009	0.0025 0.0008 -0.0017	0.0015 0.0002 -0.0025	0.0051 0.0046 0.0056	0.0079 0.0074 0.0085	0.0097 0.0092 0.0104	0.0032 0.0031 0.0019	0.0032 0.0033 0.0020	0.0031 0.0029 0.0018
AVERAGE	0.0012	0.0005	-0.0003	0.0051	0.0079	0.0098	0.0027	0.0028	0.0026
AMBIENT (NOM. 72°)	0.0005 0.0003 0.0019	-0.0024 -0.0027 -0.0010	-0.0055 -0.0057 -0.0039	0.0056 0.0050 0.0041	0.0073 0.0067 0.0058	0.0081 0.0076 0.0067	0.0016 0.0019 0.0010	-0.0001 0.0003 -0.0007	-0.0019 -0.0018 -0.0028
AVERAGE	0.0009	-0.0020	-0.0050	0.0049	0.0066	0.0075	0.0015	-0.0002	-0.0022
200	0.0026 -0.0001 0.0001	-0.0005 -0.0044 -0.0042	-0.0061 -0.0093 -0.0088	0.0059 0.0059 0.0063	0.0094 0.0071 0.0076	0.0090 0.0068 0.0079	0.0035 0.0011 0.0035	0.0023 -0.0006 0.0014	-0.0011 -0.0038 -0.0012
AVERAGE	0.0009	-0.0030	-0.0081	0.0060	0.0080	0.0079	0.0027	0.0010	-0.0020

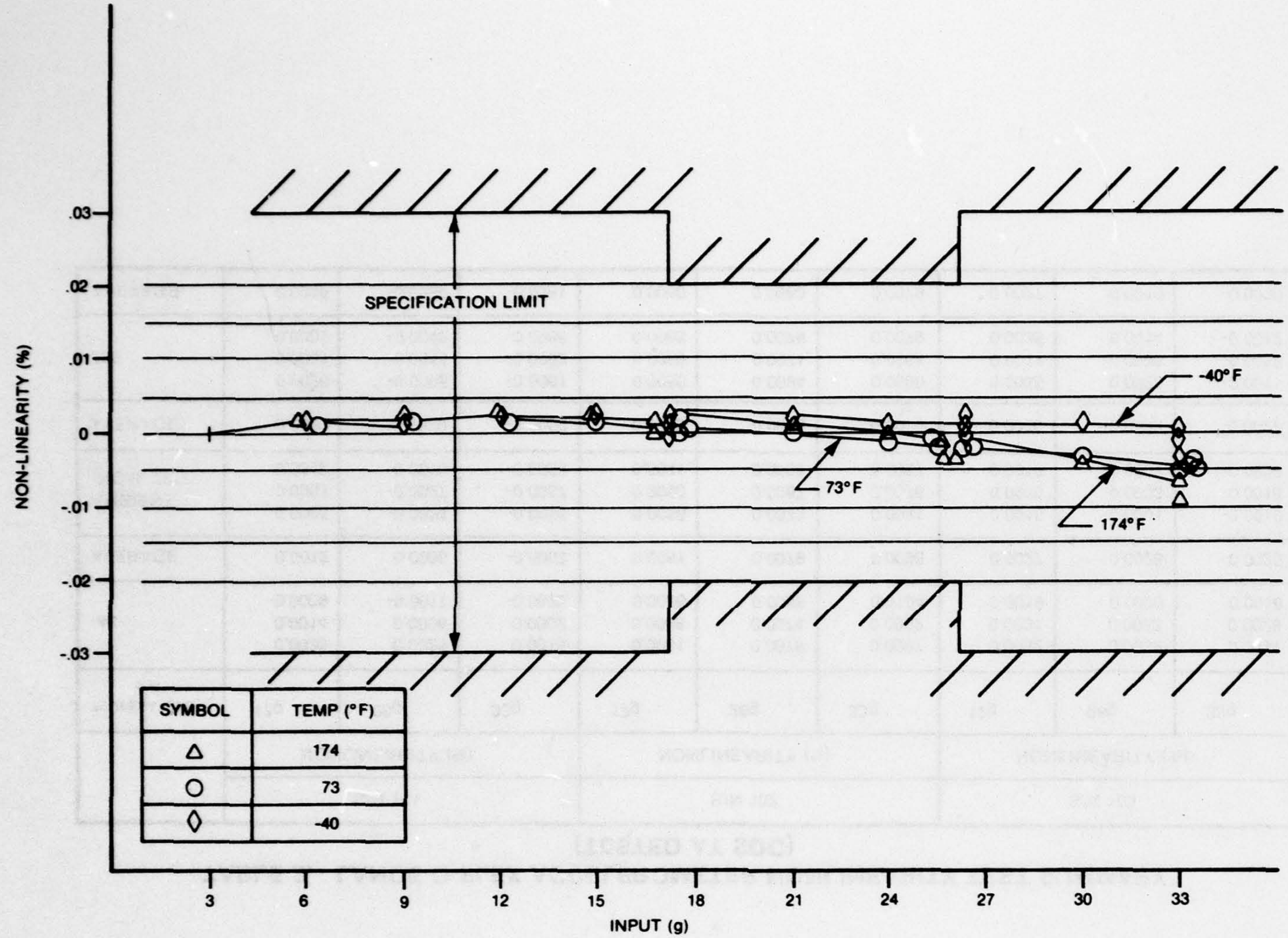

Figure 1. Lance TIP accelerometer design verification high-g linearity conducted on SDC centrifuge (S/N 101).

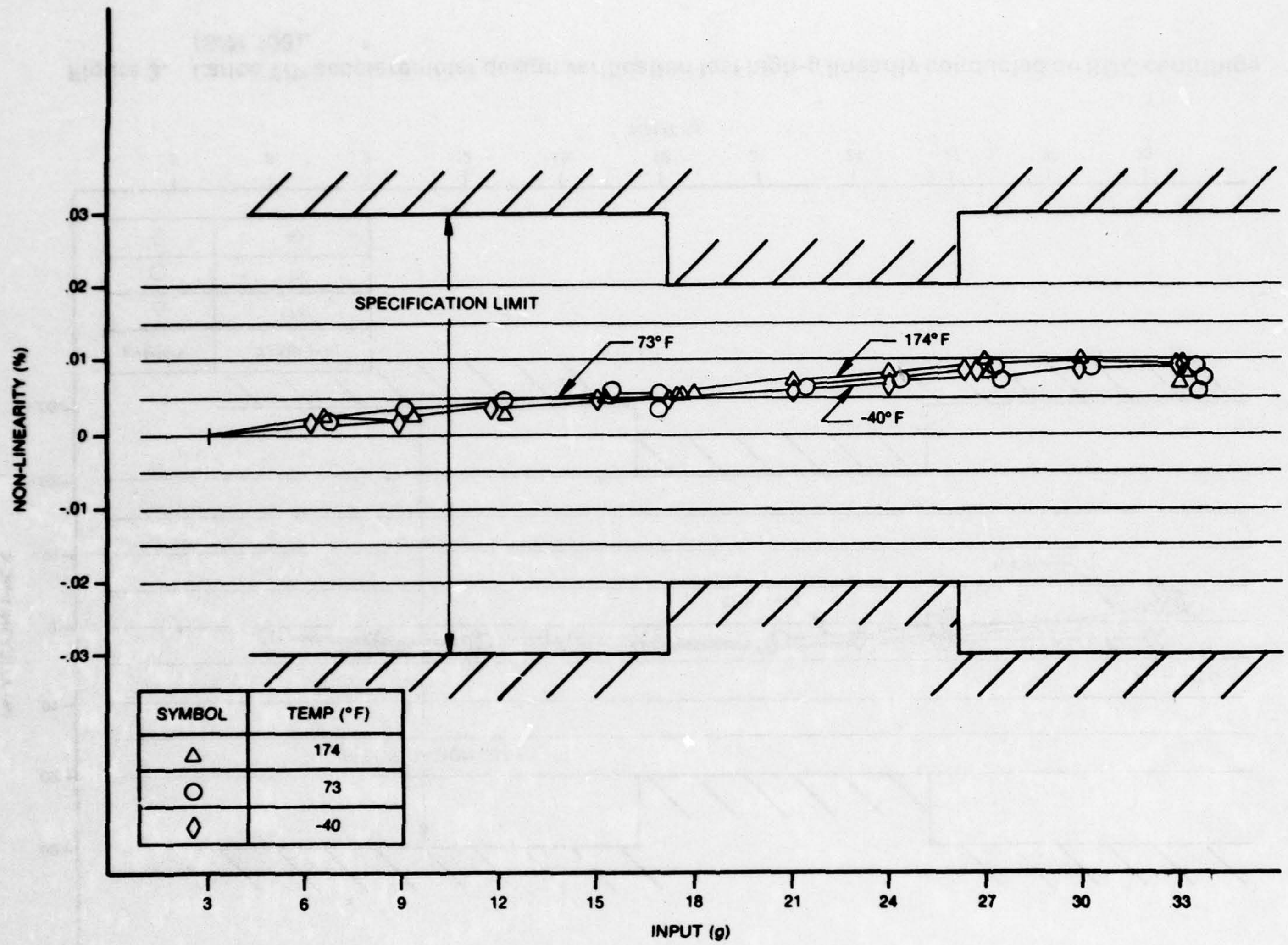

Figure 2. **Lance TIP accelerometer design verification test high-g linearity conducted on SDC centrifuge (S/N 102).**

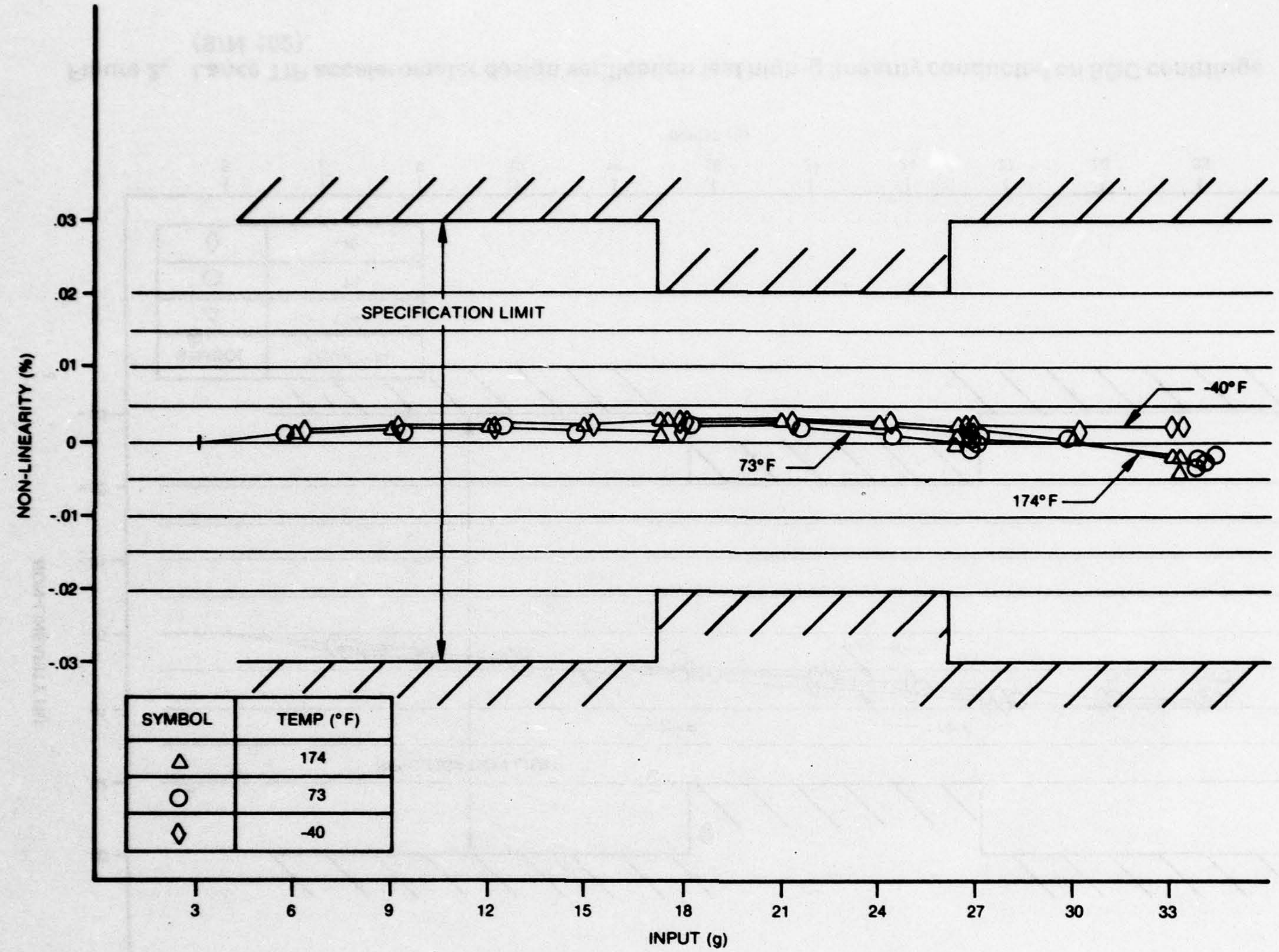

Figure 3. **Lance TIP accelerometer design verification test high-g linearity conducted on SDC centrifuge (S/N 103).**

TABLE 3. LANCE BIAS VALUES*

UNIT S/N	INITIAL VALUE (μg)	FINAL VALUE (μg)	EXTREME VALUES MAX (μg)	MIN (μg)
101	5	-28	34	-55
102	-23	-48	16	-60
103	24	27	57	-12

*Distribution summary. All values after bias trim. All environments.

TABLE 4. SUMMARY OF ACCELEROMETER PERFORMANCE CHARACTERISTICS

	SF AND BIAS RELATED VALUES				ALIGNMENT TC		NONLINEARITY (%)			SPIN SENS.
UNIT S/N	SF (V/g)	BIAS (mg)	SFTC (%/°F)	BTC (mg/°F)	VERT (mr/°F)	HORIZ (mr/°F)	33g (-40°F)	33g (amb)	33g (200°F)	mg/RPS²
101	0.499907	-0.009	0.0001	1.4	0.001	0.000	—	-0.013	-0.017	-0.020
102	0.499906	-0.039	0.0000	0.4	0.000	0.000	—	-0.003	0.001	0.032
103	0.499926	0.030	0.0002	0.3	0.000	0.000	-0.010	-0.015	-0.009	0.025
SPEC	0.50000 ±0.00125	0.200 ABS	0.0100	6.0	0.010	0.010	±0.030	±0.030	±0.030	0.044

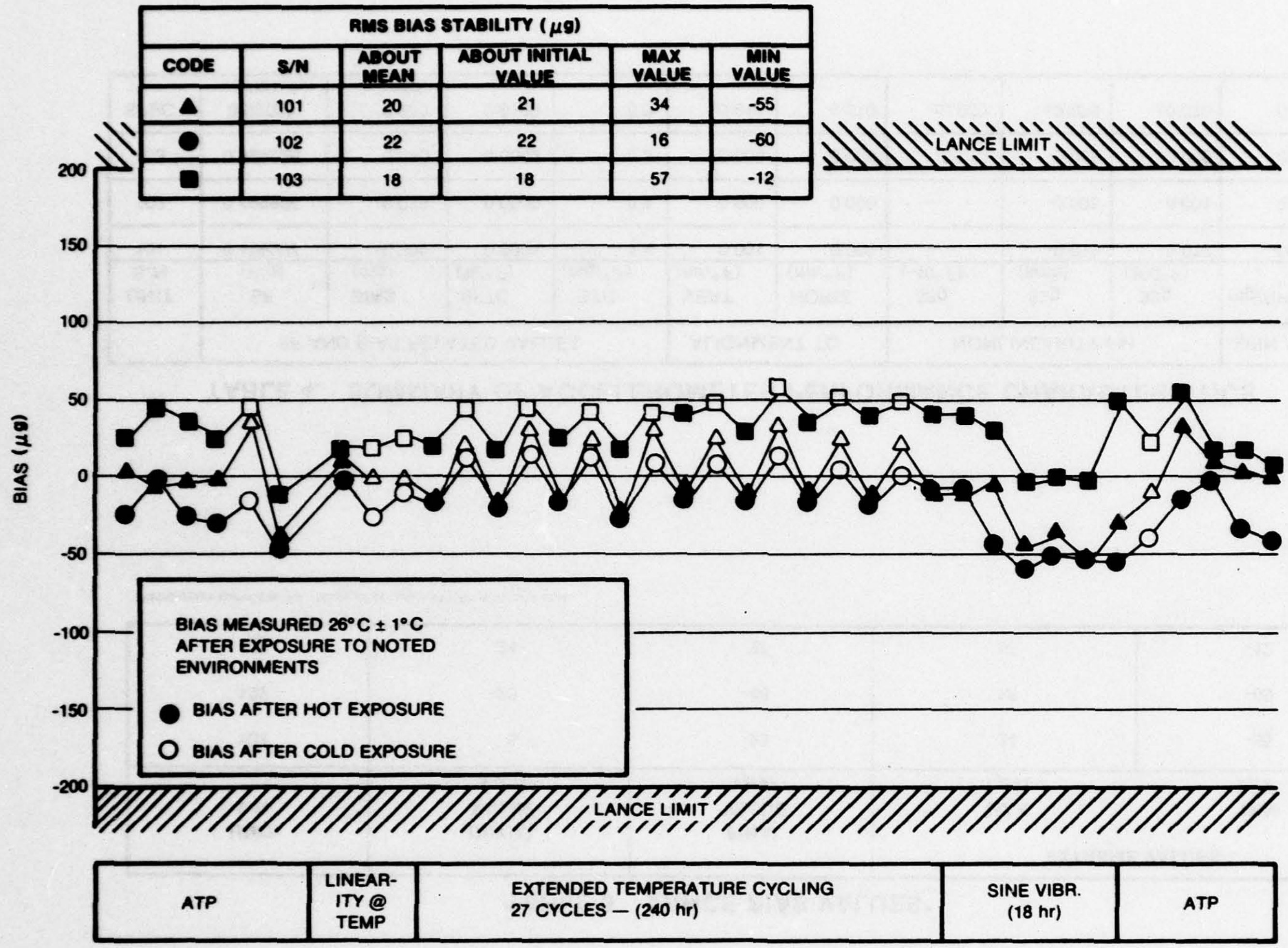

Figure 4. Bias variation over all environments.

equal to or greater than two orders of magnitude better than the design specification on two out of three of the units tested. The Negative Temperature Coefficient Resistor (NTCR) performed exceptionally well in reducing the accelerometer SFTC characteristic. Bias Temperature Coefficienct (BTC) performance was also well within the design specification requirements. Both SFTC and BTC results are averages taken over the -40° F to 200° F temperature operating range. Scale factor and bias temperature coefficients for -40° F temperature increments are given in Appendix A. The changes in vertical and horizontal axis alignment temperature coefficients over the operating temperature range are negligible. Vertical and horizontal alignment temperature coefficients for -40° F temperature increments are contained in Appendix B. Nonlinearity tests were performed at -40° F, ambient and 200° F temperatures on S/N 103. Serial numbers 101 and 102 were subjected to nonlinearity testing at ambient and 200° F temperatures only. A summary of the nonlinearity results obtained on all three accelerometers is contained in *Table 4*. Spin sensitivity is the only parameter measured which was near the Lance specification limit. The spin sensitivity test results obtained at MIRADCOM (*Table 4*) were almost identical to the results obtained at SDC (*Table 1*).

The results of the complete nonlinearity tests series on the three accelerometers evaluated at MIRADCOM are contained in *Table 5*. Comparing these test results with the results obtained at SDC's facility, it is noted that there is an average difference of approximately 0.012% (i.e., the results obtained at SDC were approximately 0.012% more positive than MIRADCOM's test results). However, the results obtained at both facilities were well within Lance specifications. *Figures 5* and *6* show the nonlinearity of S/N's 101 and 102 at ambient temperatures at the high temperature extreme. *Figure 7* shows the nonlinearity of S/N 103 at ambient temperature and the two temperature extremes.

The bias thermal hysteresis (BTH) test results on the three accelerometers are shown in *Figures 8* through *10*. The instruments were stabilized at the hot (200° F) and cold (-40° F) temperatures for a nominal 4 hours each. The initial bias reading (153 μg) taken on S/N 101 after 16 hours of stabilization at ambient temperature during run 5 (*Figure 8*) is assumed to be in error. The unit was allowed to remain at ambient over a weekend for a total of 64 hours when a bias reading of 12 μg above the run 0 bias was recorded. Fifteen additional runs were taken on S/N 101 without incurring any large

TABLE 5. LANCE Q-FLEX ACCELEROMETER NONLINEARITY TEST SUMMARY (TESTED AT MIRADCOM)

	S/N 101			S/N 102			S/N 103		
	NONLINEARITY (%)			NONLINEARITY (%)			NONLINEARITY (%)		
TEMPERATURE (°F)	17g	26g	33g	17g	26g	33g	17g	26g	33g
-40							-0.0101 -0.0044	-0.0110 -0.0085	-0.0108 -0.0092
AVERAGE							-0.0073	-0.0098	-0.0100
AMBIENT (NOM. 72)	-0.0085 -0.0076 -0.0069	-0.0111 -0.0105 -0.0113	-0.0106 -0.0147 -0.0134	-0.0079 -0.0062 -0.0043	-0.0056 -0.0027 -0.0027	-0.0029 -0.0048 -0.0021	-0.0133 -0.0141 -0.0107	-0.0137 -0.0130 -0.0102	-0.0146 -0.0152 -0.0146
AVERAGE	-0.0077	-0.0110	-0.0129	-0.0061	-0.0037	-0.0033	-0.0127	-0.0123	-0.0148
200	-0.0141 -0.0076	-0.0197 -0.0105	-0.0235 -0.0103	-0.0043 -0.0014	-0.0005 0.0032	-0.0044 0.0055	-0.0073 -0.0045	-0.0062 -0.0079	-0.0098 -0.0091
AVERAGE	-0.0108	-0.0151	-0.0169	-0.0029	0.0014	0.0006	-0.0059	-0.0070	-0.0094

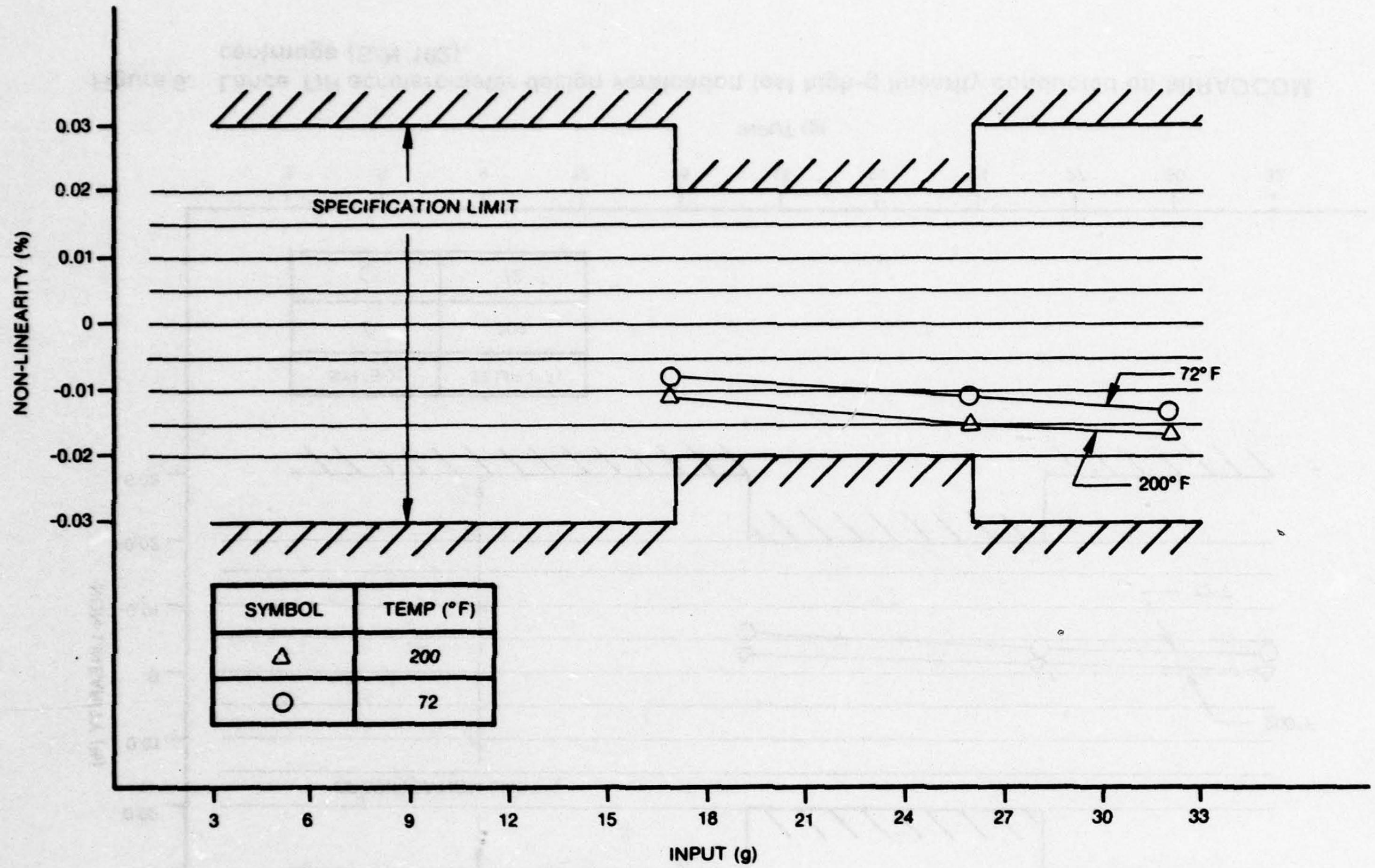

Figure 5. **Lance TIP accelerometer design verification test high-g linearity conducted on MIRADCOM centrifuge (S/N 101).**

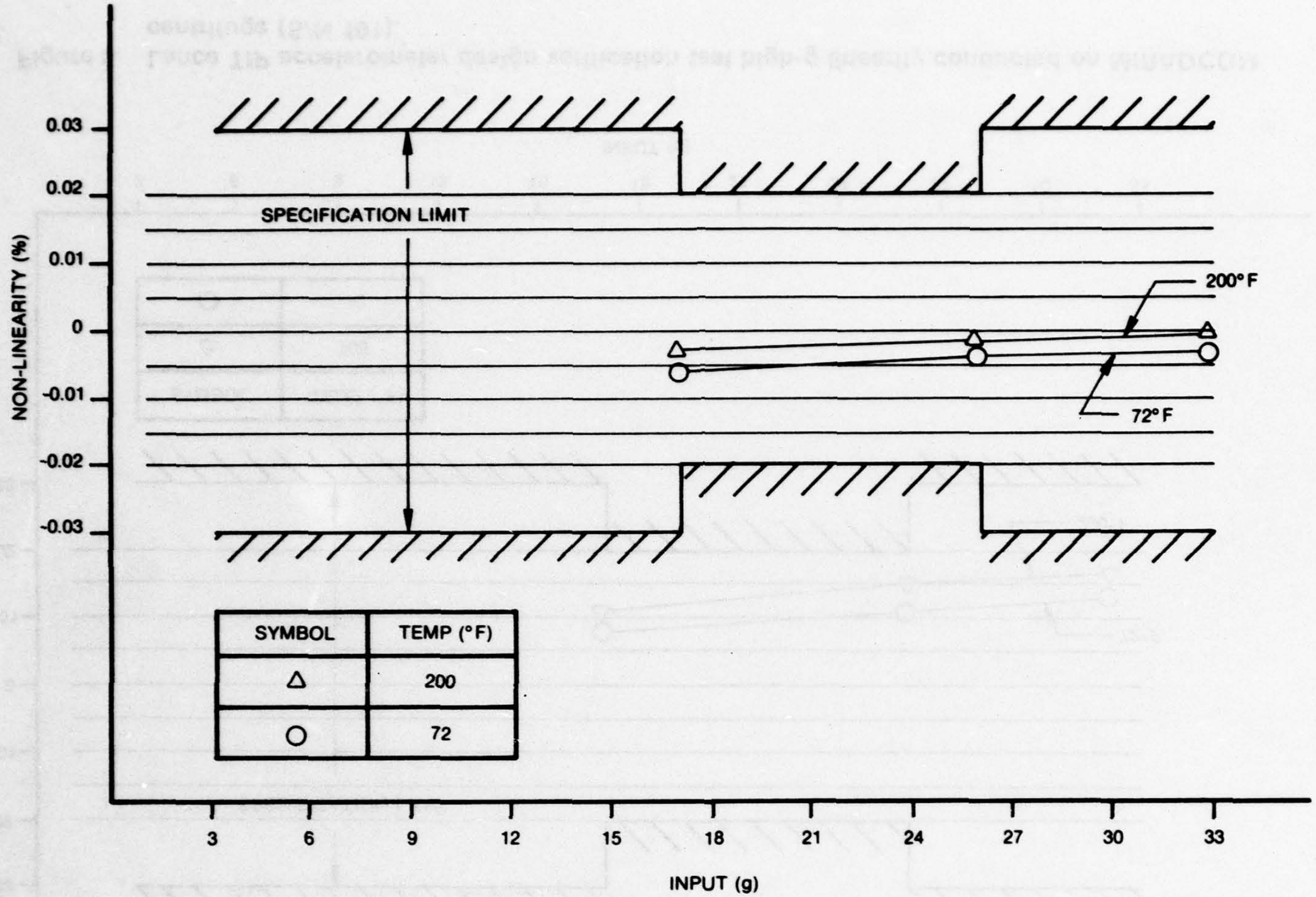

Figure 6. **Lance TIP accelerometer design verification test high-g linearity conducted on MIRADCOM centrifuge (S/N 102).**

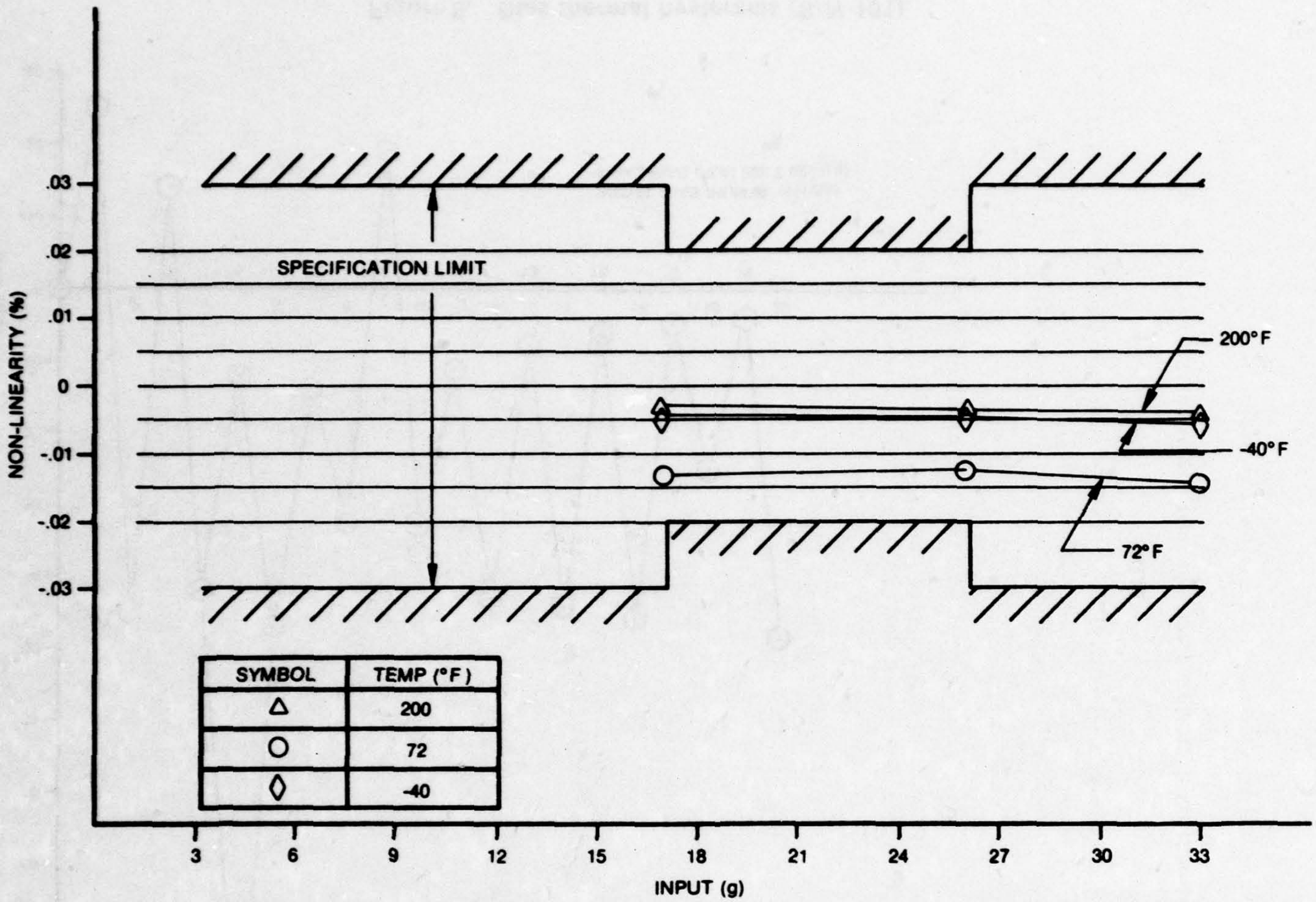

Figure 7. Lance TIP accelerometer design verification test high-g linearity conducted on MIRADCOM centrifuge (S/N 103).

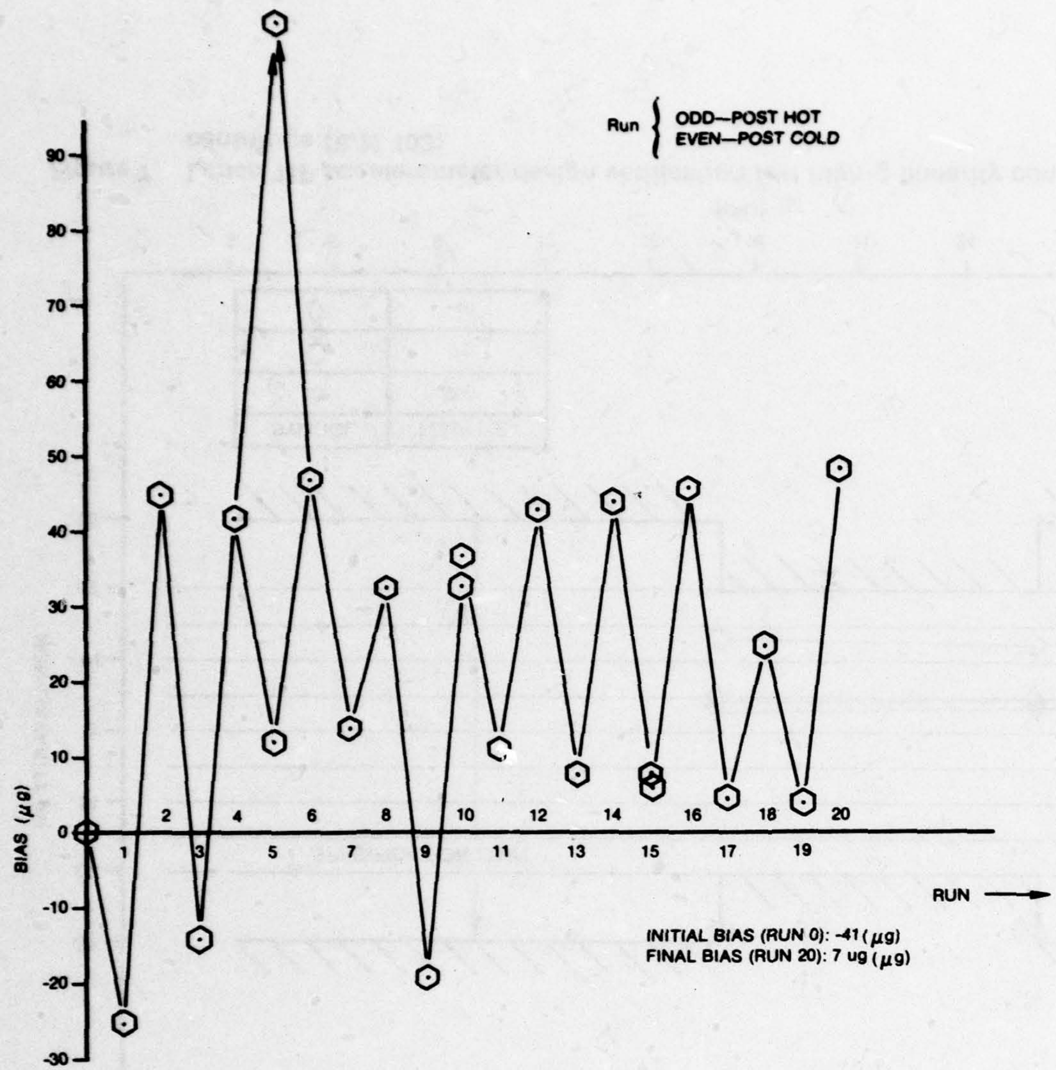

Figure 8. **Bias thermal hysteresis (S/N 101).**

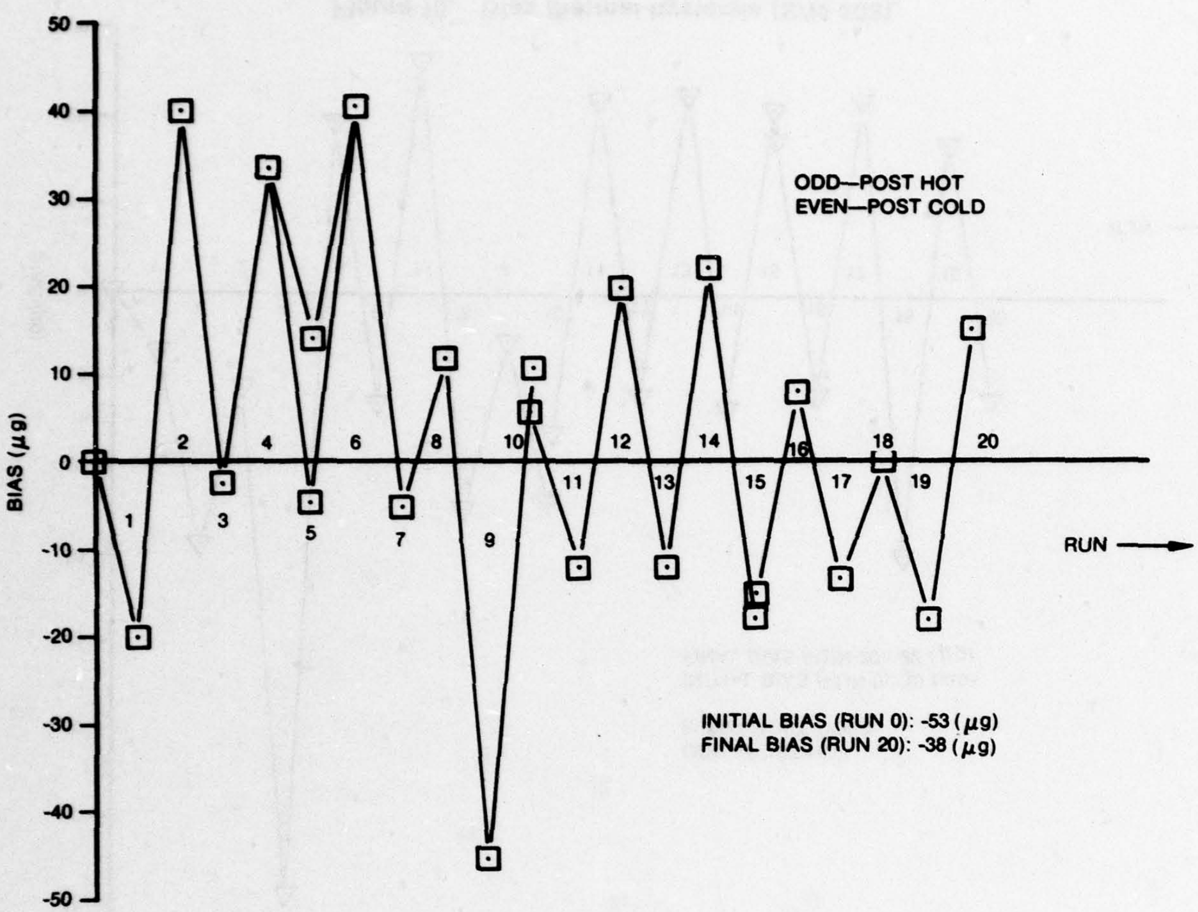

Figure 9. Bias thermal hysteresis (S/N 102).

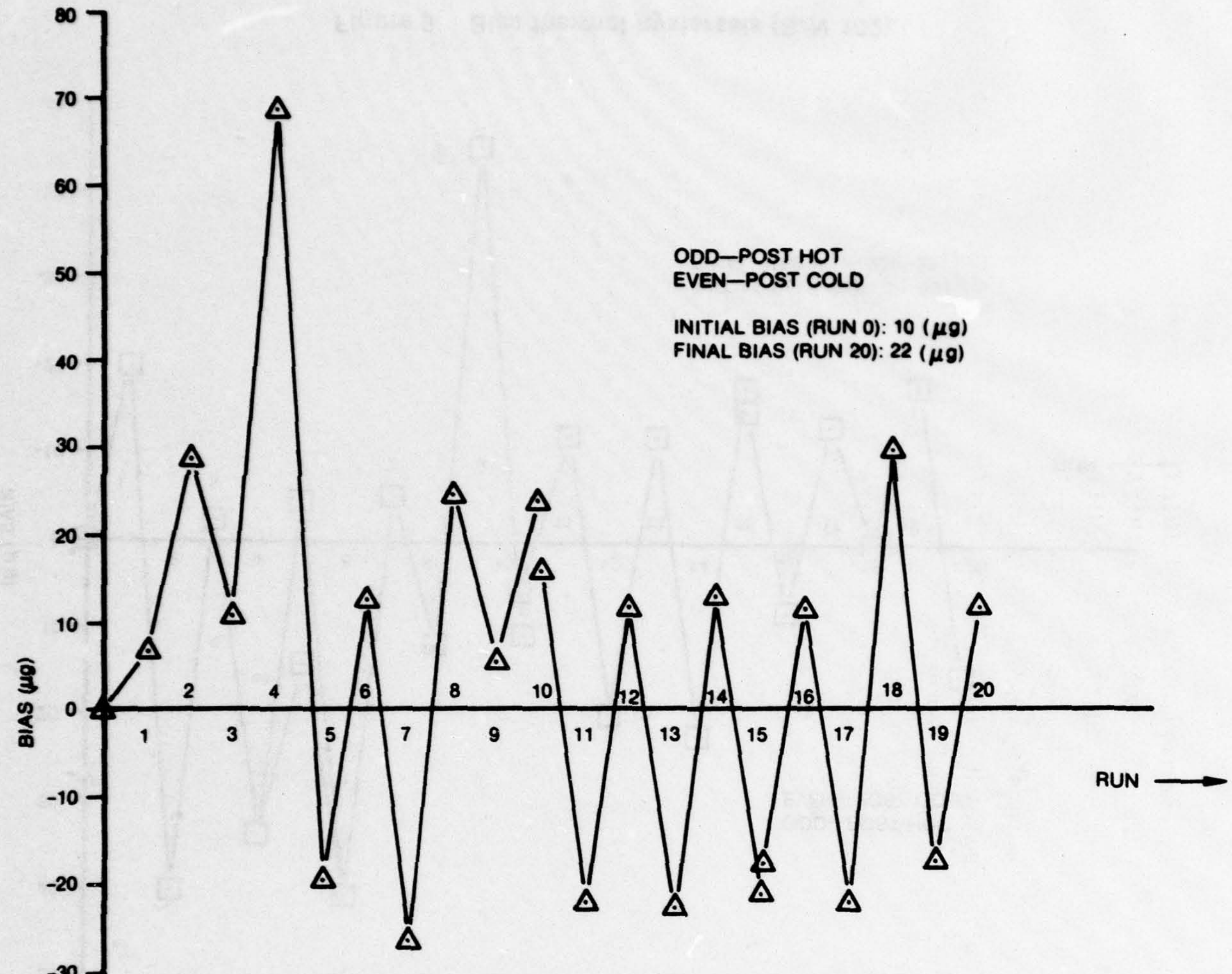

Figure 10. Bias thermal hystersis (S/N 103).

shifts. All post hot and cold readings were taken after at least four hours of stabilization at ambient temperatures.

Scale factor hysteresis information is presented in *Figures 11* through *13*. There appears to be a slight trend of increasing scale factor (5.8 to 7.3 $\mu V/g$ per nanoscript) on each of the three accelerometers as they progress through the series of hot and cold environments.

The last test series to be conducted was scale factor .and bias stability through non-operating vibration. Ten scale factor and bias runs were made before and after the units were subjected to the non-operational vibration environment specified in the Lance Accelerometer MIS. The three accelerometers were vibrated along each of the three orthogonal axes. Test results are presented in *Tables 6, 7* and *8*.

4. CONCLUSIONS AND RECOMMENDATIONS

Table 9 presents an abbreviated summary of the tests conducted at SDC and MIRADCOM and can be used for a quick comparison between the test results from both facilities. All parameters listed in *Table 9* meet the requirements outlined in the Lance MIS.

The bias thermal hysteresis design goal of ± 50 μg's from the initial bias reading was met on every run except one. Run 4 on S/N 103 showed a deviation of 68 μg's. This value, however, was still within the Lance specification of 200 μg's absolute.

The overall design, fabrication and test program on the Lance Q-Flex Accelerometer has been a success.

It is recommended that additional scale factor hysteresis tests be conducted on the accelerometers to establish the trend reversal. It is also recommended that the source of the nonlinearity difference between the SDC and MIRADCOM centrifuge be determined.

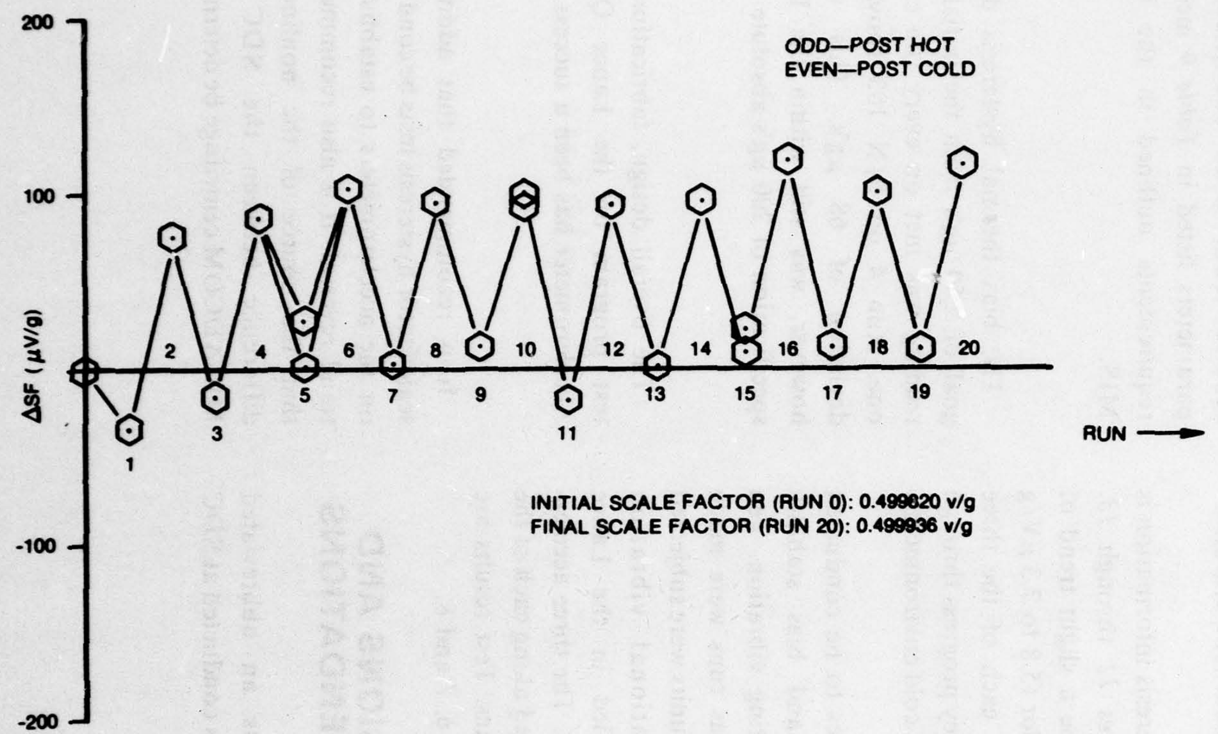

Figure 11. Scale factor thermal hysteresis (S/N 101).

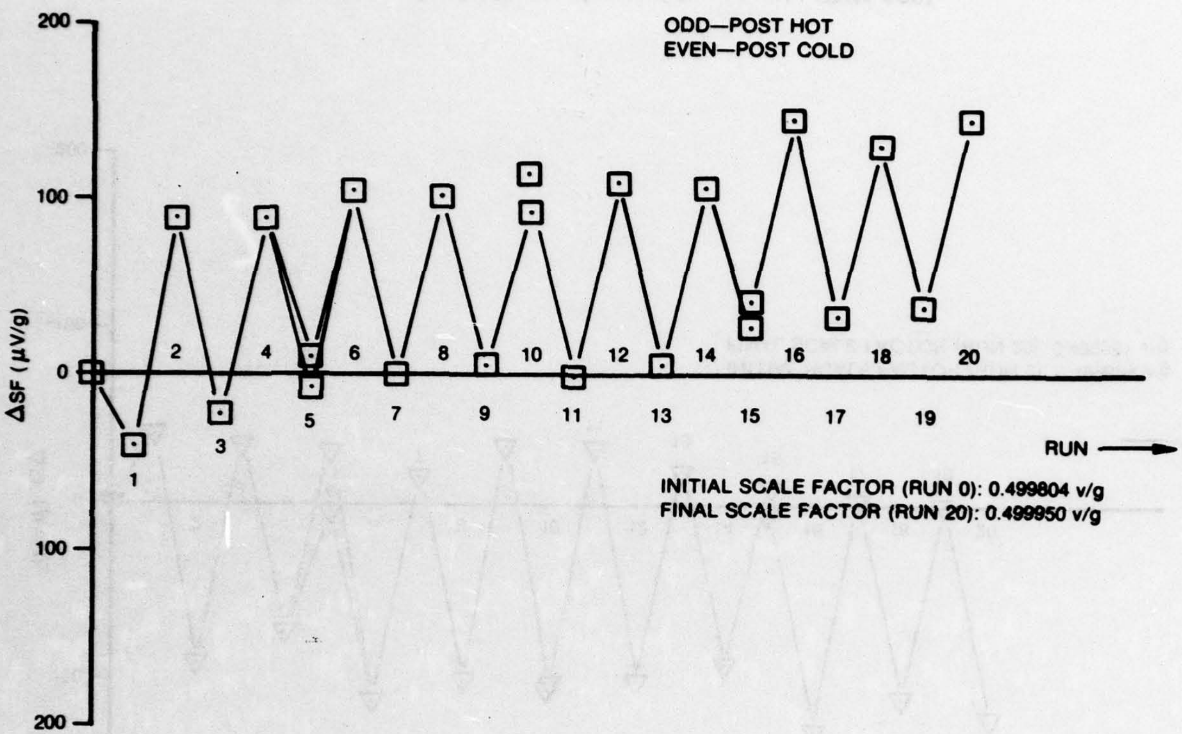

Figure 12. Scale factor thermal hysteresis (S/N 102).

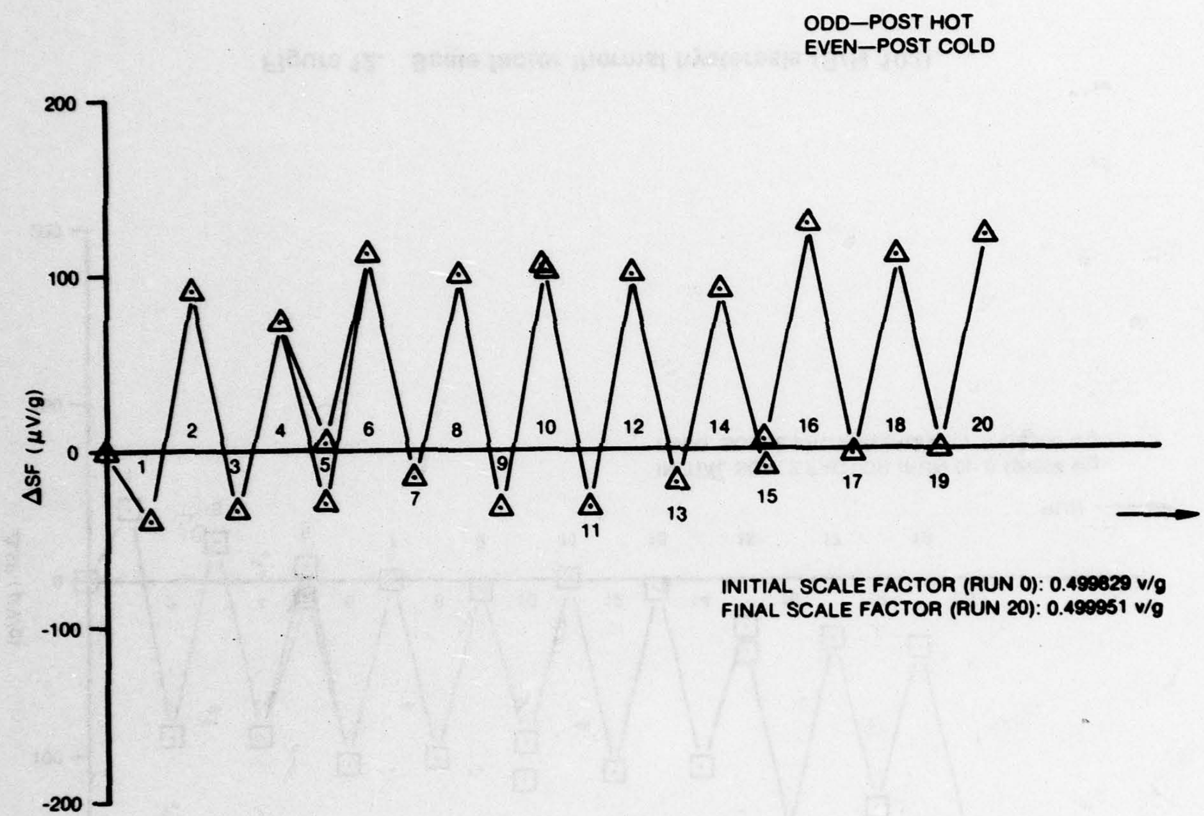

Figure 13. Scale factor thermal hysteresis (S/N 103).

TABLE 6. SCALE FACTOR AND BIAS STABILITY THROUGH NON-OPERATING VIBRATION (S/N 101)

S/N 101 SCALE FACTOR AND BIAS BEFORE NON-OP. SINE SWEEP AND SINUSOIDAL DWELL					
RUN NO.	Vo (+ 1g)	Vo (- 1g)	S.F. (V/g)	BIAS (μg)	AVG. TEMP. (°F)
1	0.499850	0.499880	0.499865	-30	72
2	0.499862	0.499888	0.499875	-26	72
3	0.499863	0.499890	0.499877	-27	72
4	0.499862	0.499892	0.499877	-30	72
5	0.499862	0.499892	0.499877	-30	72
6	0.499866	0.499884	0.499875	-26	72
7	0.499859	0.499890	0.499875	-31	72
8	0.499859	0.499890	0.499875	-31	72
9	0.499857	0.499892	0.499875	-35	72
10	0.499860	0.499883	0.499872	-23	72
AVG	0.499860	0.499888	0.499874	-28.9	
AFTER SINE SWEEP AND SINUSOIDAL DWELL					
1	0.499860	0.499888	0.499874	-28	71
2	0.499858	0.499886	0.499872	-28	71
3	0.499860	0.499887	0.499874	-27	71
4	0.499859	0.499888	0.499874	-29	71
5	0.499860	0.499890	0.499875	-30	71
6	0.499861	0.499888	0.499875	-27	71
7	0.499860	0.499889	0.499875	-29	71
8	0.499861	0.499890	0.499876	-29	71
9	0.499861	0.499889	0.499875	-28	71
10	0.499861	0.499890	0.499876	-29	71
AVG	0.499860	0.499889	0.499875	-28.4	

TABLE 7. SCALE FACTOR AND BIAS STABILITY THROUGH NON-OPERATING VIBRATION (S/N 102)

RUN NO.	Vo (+ 1g)	Vo (- 1g)	S. F. (V/g)	BIAS (μg)	AVG. TEMP. (°F)
S/N 102 SCALE FACTOR AND BIAS BEFORE NON-OP. SINE SWEEP AND SINUSOIDAL DWELL					
1	0.499857	-0.499914	0.499886	-57	72
2	0.499860	-0.499916	0.499888	-56	72
3	0.499857	-0.499917	0.499887	-60	72
4	0.499857	-0.499920	0.499889	-63	72
5	0.499857	-0.499920	0.499889	-63	72
6	0.499858	-0.499922	0.499890	-64	72
7	0.499855	-0.499920	0.499888	-65	72
8	0.499853	-0.499919	0.499886	-66	72
9	0.499853	-0.499921	0.499887	-68	72
10	0.499852	-0.499920	0.499886	-68	72
AVG	0.499856	-0.499919	0.499888	-63	
AFTER SINE SWEEP AND SINUSOIDAL DWELL					
1	0.499850	0.499910	0.499880	-60	69
2	0.499848	0.499912	0.499880	-64	69
3	0.499849	0.499913	0.499881	-64	69
4	0.499849	0.499915	0.499882	-66	69
5	0.499849	0.499916	0.499883	-67	69
6	0.499850	0.499916	0.499883	-66	69
7	0.499850	0.499919	0.499885	-69	69
8	0.499848	0.499918	0.499883	-70	
9	0.499848	0.499916	0.499882	-68	69
10	0.499848	0.499918	0.499883	-70	69
AVG	0.499849	0.499915	0.499882	-66.4	

TABLE 8. SCALE FACTOR AND BIAS STABILITY THROUGH NON-OPERATING VIBRATION (S/N 103)

S/N 103 SCALE FACTOR AND BIAS BEFORE NON-OP. SINE SWEEP AND SINUSOIDAL DWELL					
RUN NO.	Vo (+ 1g)	Vo (- 1g)	S.F. (V/g)	BIAS (μg)	AVG. TEMP. (°F)
1	0.499869	0.499837	0.499853	32	72
2	0.499874	0.499836	0.499855	38	72
3	0.499877	0.499837	0.499857	40	72
4	0.499879	0.499839	0.499859	40	72
5	0.499878	0.499839	0.499859	39	72
6	0.499878	0.499839	0.499859	39	72
7	0.499879	0.499838	0.499859	41	72
8	0.499876	0.499839	0.499858	37	72
9	0.499876	0.499839	0.499858	37	72
10	0.499875	0.499837	0.499856	38	72
AVG	0.499876	0.499838	0.499857	38.1	
AFTER SINE SWEEP AND SINUSOIDAL DWELL					
1	0.499882	0.499839	0.499861	43	72
2	0.499880	0.499838	0.499859	52	72
3	0.499880	0.499838	0.499859	42	72
4	0.499881	0.499839	0.499860	42	72
5	0.499881	0.499839	0.499860	42	72
6	0.499883	0.499840	0.499862	43	72
7	0.499882	0.499839	0.499861	43	72
8	0.499884	0.499840	0.499862	44	72
9	0.499886	0.499841	0.499864	45	72
10	0.499886	0.499840	0.499863	46	72
AVG	0.499883	0.499839	0.499861	43.2	

TABLE 9. SUMMARY OF TESTS CONDUCTED AT SDC AND MIRADCOM

PERFORMANCE PARAMETER	SPEC. VALUE	S/N 101		S/N 102		S/N 103	
		SDC	MIRADCOM	SDC	MIRADCOM	SDC	MIRADCOM
*SCALE FACTOR (V/g)	0.5 ± 0.25%	0.499960	0.499907	0.499970	0.499906	0.499970	0.499926
*BIAS (μg)	200 ABS	-37	-9	-45	-39	-12	30
▲SFTC (%/°F)	0.0100	0.0002	0.0001	0.0002	0.0000	0.00025	0.0002
▲BTC (μg/°F)	6	1.5	1.4	0.4	0.4	0.5	0.3
VERT MISAL (mr)	0.500	0.043	—	-0.065	—	0.004	—
HORIZ MISAL (mr)	1.50	-0.003	—	0.025	—	-0.007	—
VMTC (mr/°F)	0.010	—	0.001	—	0.000	—	0.000
HMTC (mr/°F)	0.010	—	0.000	—	0.000	—	0.000
NONLIN. at 33g (%)	0.030	-0.0050	-0.013	0.0075	-0.003	-0.0022	-0.015
VRC at 5.3g (mg/g²)	0.160	-0.001	—	-0.002	—	0.001	—
SPIN SEN (mg/RPS²)	0.044	-0.020	-0.020	0.034	0.032	0.025	0.025
▲ECM (inches)	0.050	0.025	—	0.025	—	0.018	—
BIAS TH. HYSTERESIS							
INITIAL BIAS (μg)	200 ABS	5	-41	-23	-53	24	10
FINAL BIAS (μg)	200 ABS	-28	7	-48	-38	27	22
BIAS EXTREMES							
MIN BIAS (μg)	200 ABS	-55	-66	-60	-98	-12	-16
MAX BIAS (μg)	200 ABS	34	7	16	-12	57	79
S.F. TH HYSTERESIS							
INITIAL S.F. (V/g)	0.5 ± 0.25%		0.499820		0.499804		0.499829
FINAL S.F. (V/g)	0.5 ± 0.25%		0.499936		0.499950		0.499951
S.F. EXTREMES							
MIN S.F. (V/g)	0.5 ± 0.25%		0.499726		0.499764		0.499790
MAX S.F. (V/g)	0.5 ± 0.25%		0.499940		0.499950		0.499958
BIAS: BEFORE VIB.	200 ABS		-28.9		-63.0		38.1
AFTER VIB.	200 ABS		-28.4		-66.4		43.2
S.F.: BEFORE VIB.	0.5 ± 0.25%		0.499874		0.499888		0.499857
AFTER VIB.	0.5 ± 0.25%		0.499875		0.499882		0.499861

* INITIAL VALUES (BEFORE ENVIRONMENTAL TESTS)
▲ AVERAGE OF BEFORE AND AFTER ENVIRONMENTAL TEST RESULTS

APPENDIX A

SCALE FACTOR AND BIAS TEMPERATURE COEFFICIENT TEST DATA

TEMP °F	S/N 101 SCALE FACTOR AND BIAS TESTS				S.F. TEMP. SENS. (%/°F)	BIAS TEMP. SENS. (μg/°F)
	Vo (+ 1g)	Vo (-1g)	S.F. (V/g)	BIAS (μg)		
-40	0.499765	-0.499957	0.499861	-192		
	0.499769	-0.499964	0.499867	-195		
	0.499773	-0.499966	0.499870	-193		
	AVERAGE S.F. & BIAS		0.499866	-193		
0	0.499839	-0.499964	0.499902	-127		
	0.499843	-0.499965	0.499904	-122		
	0.499844	-0.499968	0.499906	-124		
	AVERAGE S.F. & BIAS		0.499904	-124	0.0002	1.72
40	0.499856	-0.499938	0.499897	-82		
	0.499855	-0.499939	0.499897	-84		
	0.499865	-0.499941	0.499903	-76		
	AVERAGE S.F. & BIAS		0.499899	-81	0.0000	1.07
80	0.499923	-0.499939	0.499931	-16		
	0.499931	-0.499940	0.499936	-9		
	0.499928	-0.499940	0.499934	-12		
	AVERAGE S.F. & BIAS		0.499934	-12	0.0002	1.72
120	0.499916	-0.499878	0.499897	38		
	0.499933	-0.499890	0.499912	43		
	0.499924	-0.499882	0.499903	42		
	AVERAGE S.F. & BIAS		0.499904	41	-0.0002	1.32
160	0.499835	-0.499754	0.499795	81		
	0.499838	-0.499757	0.499798	81		
	0.499839	-0.499760	0.499800	82		
	AVERAGE S.F. & BIAS		0.499798	81	-0.0005	1.00
200	0.499825	-0.499675	0.499750	150		
	0.499824	-0.499669	0.499747	155		
	0.499826	-0.499678	0.499752	148		
	AVERAGE S.F. & BIAS		0.499750	151	-0.0002	1.75
SPEC					±0.010%/°F	±6μg/°F

TEMP °F	S/N 102 SCALE FACTOR AND BIAS TESTS				S.F. TEMP. SENS. (%/° F)	BIAS TEMP. SENS. (μg/° F)
	Vo (+ 1g)	Vo (-1g)	S.F. (V/g)	BIAS (μg)		
-40	0.499854	-0.499825	0.499840	29		
	0.499862	-0.499840	0.499851	37		
	0.499860	-0.499843	0.499852	17		
	AVERAGE S.F. & BIAS		0.499848	28		
0	0.499899	-0.499906	0.499903	-8		
	0.499893	-0.499907	0.499900	-14		
	0.499894	-0.499911	0.499903	-17		
	AVERAGE S.F. & BIAS		0.499902	-13	0.0003	-1.02
40	0.499884	-0.499927	0.499906	-43		
	0.499886	-0.499930	0.499908	-44		
	0.499886	-0.499932	0.499909	-46		
	AVERAGE S.F. & BIAS		0.499908	-44	0.0000	-0.78
80	0.499936	-0.499978	0.499957	-42		
	0.499934	-0.499978	0.499956	-44		
	0.499934	-0.499978	0.499956	-44		
	AVERAGE S.F. & BIAS		0.499956	-43	0.0002	-0.02
120	0.499905	-0.499960	0.499933	-55		
	0.499904	-0.499965	0.499935	-61		
	0.499902	-0.499961	0.499932	-59		
	AVERAGE S.F. & BIAS		0.499933	-58	-0.0001	-0.38
160	0.499816	-0.499876	0.499846	-60		
	0.499815	-0.499875	0.499845	-60		
	0.499815	-0.499874	0.499845	-59		
	AVERAGE S.F. & BIAS		0.499845	-60	-0.0004	-0.05
200	0.499781	-0.499825	0.499803	-44		
	0.499790	-0.499836	0.499813	-46		
	0.499782	-0.499833	0.499808	-51		
	AVERAGE S.F. & BIAS		0.499808	-47	-0.0002	0.32
SPEC					± 0.010%/° F	± 6 μg/° F

TEMP °F	S/N 103 SCALE FACTOR AND BIAS TESTS				S.F. TEMP SENS. (%/°F)	BIAS TEMP SENS. (μg/°F)
	Vo (+1g)	Vo (−1g)	S.F. (V/g)	BIAS (μg)		
-40	0.499969	-0.499883	0.499926	86		
	0.499977	-0.499887	0.499932	94		
	0.499982	-0.499884	0.499933	99		
	AVERAGE SF & BIAS		0.499930	93		
0	0.499991	-0.499809	0.499900	182		
	0.499995	-0.499892	0.499944	103		
	0.499986	-0.499888	0.499937	94		
	AVERAGE SF & BIAS		0.499927	126	0.0000	0.82
40	0.499926	-0.499788	0.499857	138		
	0.499930	-0.499789	0.499860	141		
	0.499931	-0.499871	0.499901	60		
	AVERAGE SF & BIAS		0.499873	113	-0.0003	-0.32
80	0.499940	0.499902	0.499921	38		
	0.499940	0.499899	0.499920	41		
	0.499941	0.499896	0.499919	45		
	AVERAGE SF & BIAS		0.499920	41	0.0002	-1.80
120	0.499880	0.499865	0.499873	15		
	0.499880	0.499862	0.499871	18		
	0.499883	0.499864	0.499874	19		
	AVERAGE SF & BIAS		0.499873	17	-0.0002	-0.60
160	0.499759	0.499759	0.499759	0		
	0.499757	0.499758	0.499758	1		
	0.499760	0.499757	0.499759	3		
	AVERAGE SF & BIAS		0.499759	1	-0.0006	-0.40
200	0.499724	0.499714	0.499719	10		
	0.499726	0.499712	0.499719	14		
	0.499725	0.499709	0.499717	16		
	AVERAGE SF & BIAS		0.499719	13	-0.0002	0.30
SPEC					±0.010%/°F	±6 Mg/°F

APPENDIX B

VERTICAL AND HORIZONTAL ALIGNMENT TEMPERATURE SENSITIVITY TEST RESULTS

TEMP (°F)	S/N 101		S/N 102		S/N 103	
	VA TEMP SEN. (mr/°F)	HA TEMP SEN. (mr/°F)	VA TEMP SEN. (mr/°F)	HA TEMP SEN. (mr/°F)	VA TEMP SEN. (mr/°F)	HA TEMP SEN. (mr/°F)
−40 to 0	0.001	0.003	0.001	0.000	0.001	0.000
0 to 40	0.001	0.000	−0.001	0.000	0.000	0.000
40 to 80	0.001	0.001	0.000	0.000	0.000	0.000
80 to 120	0.001	0.000	0.000	0.001	−0.001	0.000
120 to 160	0.000	0.001	0.000	0.001	0.000	0.000
160 to 200	0.002	0.000	0.001	0.001	0.000	0.000
SPEC	±0.010 mr/°F					

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